CDF Note 8675

Limit on Resonant $\mathrm{t\bar{t}}$ Production in $\mathrm{p\bar{p}}$ Collisions at $\sqrt{s} = 1.96$ TeV

The CDF Collaboration
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We search for resonant top pair production in a CDF Run II data sample of approximately 1 fb^{-1}. For b-tagged $\mathrm{t\bar{t}}$ candidates in the lepton+jets decay channel, we look for unexpected structure in the spectrum of the total pair mass $\mathrm{M_{t\bar{t}}}$. The expected shape of $\mathrm{M_{t\bar{t}}}$ from Standard Model top, non-top backgrounds, and a simple resonance model, heavy $Z' \rightarrow \mathrm{t\bar{t}}$, are derived from Monte Carlo simulation and data control samples. A binned likelihood fit to the three components is performed for Z' masses from 450 $\mathrm{GeV/c^2}$ to 900 $\mathrm{GeV/c^2}$ and we establish 95% CL upper limits for $\sigma \cdot B(Z' \rightarrow \mathrm{t\bar{t}})$ as a function of the Z' mass.

Preliminary Results for Winter 2007 Conferences

I. INTRODUCTION

Large samples of reconstructable $t\bar{t}$ pairs produced in $p\bar{p}$ collisions at the Fermilab Tevatron afford the possibility of observing new unexpected top production mechanisms. Resonant top pair channels are associated with massive Z-like bosons in extended gauge theories [2, 3], Kaluza-Klein states of the Z [4], axigluons [5], and topcolor [6]. The simplest manifestation of these processes would be narrow structures in the total pair mass, $M_{t\bar{t}}$, sitting above the expected spectrum from standard s-channel gluon annihilation. The CDF and D0 collaborations set limits on these processes using very small samples at Tevtron Run I[7, 8]. Here, using techniques developed for the top mass measurement, we reconstruct $M_{t\bar{t}}$ and search for resonant $t\bar{t}$ states in 1 fb^{-1} of $\bar{p}p$ collisions at $\sqrt{s} = 1.96$ TeV. Modeling the resonance as a simple Z^0-like boson, we set limits on production cross section as a function of the pole mass. A related study using a different $M_{t\bar{t}}$ reconstruction method and 680 pb^{-1} [1] is in preparation.

II. EVENT SELECTION, DATA MODELS, BACKGROUNDS

This study is based on 955 pb^{-1} of $p\bar{p}$ collisions collected with the CDFII detector between March 2002 and January 2006. The detector [9] comprises a magnetic spectrometer in a 1.4 T field surrounded by projective electromagnetic and hadronic calorimeters and muon detectors. Near the beam, silicon microstrip detcetors provide precision track reconstruction for displaced secondary vertex detection. In the CDF coordinate system, θ is the polar angle with respect to the proton beam axis and the pseudo-rapidity is $\eta = -\ln(\tan(\theta/2))$.

We collect a sample of $t\bar{t} \rightarrow W^+bW^-\bar{b}$ decays in which one W boson decays leptonically using an inclusive lepton trigger requiring a central electron with $E_T > 18$ GeV or central muon with $P_T > 18$ GeV/c. From these triggers we select events offline with a reconstructed isolated electron E_T (muon P_T) greater than 20 GeV, missing $E_T \geq 20$ GeV and 4 jets with $| \eta | \leq 2.0$, of which 3 must have $E_T \geq 15$ GeV, and a fourth must have $E_T \geq 8$ GeV. In addition, at least one of the jets is required to be "b-tagged", containing a displaced secondary vertex which is consistent with the decay of a bottom hadron in the jet. For the 955 pb-1 data set, we find 347 candidate events.

The data sample is dominated by strong s-channel $t\bar{t}$ pair production. The $t\bar{t}$ acceptance and efficiencies are calculated using the Herwig Monte Carlo generator [11] and a CDF detector simulation, assuming $M_t = 175$ GeV$/c^2$. The model detector response, particularly with respect to lepton isolation, jet energies, and b-tagging, has been tuned in the CDF top cross section measurement [12]. The total acceptance times efficiency for a 175 GeV$/c^2$ top pair is approximately 1.5%. Non-$t\bar{t}$ backgrounds include W + jets events where a light flavor jet is incorrectly b-tagged, W+jets events with heavy flavor jets from higher order QCD, mismeasured QCD events that fake the lepton and $\not\!\!E_T$ of the W signature, and smaller contributions from electroweak processes like WW, ZZ, and single top. The rates and kinematics of these processes are separately understood and modeled using Monte Carlo and data based control samples, as employed in the CDF top cross section measurement. A total of 73 ± 9 non-top background events are expected.

Resonant $t\bar{t}$ production is modeled as a heavy neutral boson ("Z'") with the same couplings as the Z^0, decaying to 175 GeV$/c^2$ top pairs. The width of the Z' boson is taken to 1.2% of the mass. This electroweak channel has no interference with the annihilation channel, and the signal shape in $M_{t\bar{t}}$ is modified only by detector resolution and reconstruction effects. Our Z' is thus good approximation for any new state appearing as, or approximated by, a Lorentzian enhancement in a limited region of the $M_{t\bar{t}}$ spectrum. Signal models are generated using the Pythia Monte Carlo [10] with Z' masses between 450 and 900 GeV$/c^2$ in increments of 50 GeV$/c^2$.

III. RECONSTRUCTION OF THE $M_{t\bar{t}}$ DISTRIBUTION

If the parton assignments are known, the "lepton+jets" final state of 4 jets, a high p_T lepton, and $\not\!\!E_T$ allows an overconstrained reconstruction of the top pair production kinematics. The jet-parton assignment most consistent with the $t\bar{t}$ hypothesis is determined using a χ^2 minimization algorithm employed in the measurement of the top mass [13]. In the sequence $t\bar{t} \rightarrow W^+bW^-\bar{b}$, the W masses are constrained to 80.4 GeV/c^2, weighted by the W width of $\Gamma_W = 2.1$ GeV and b-tagged jets are required to be used as b's. In our analysis we also constrain the reconstructed top masses to 175 GeV$/c^2$, weighted by the top decay width of $\Gamma_t = 2.5$ GeV. The jet energies float within their expected uncertainties. The parton assignment giving the lowest χ^2 consistent with these constraints is chosen as the solution.

The reconstruction performance is studied in simulation. The "true" and reconstructed $M_{t\bar{t}}$ spectrum in the Herig $t\bar{t}$ sample is shown in Fig. 1. The reconstructed pair mass has a sharp edge at the $t\bar{t}$ threshold, and overall distribution is reasonably reproduced. Badly reconstructed events inconsistent with the $t\bar{t}$ hypothesis are removed by requiring the fit $\chi^2 > 50.0$; this cut removes 4% of Standard Model $t\bar{t}$ events.

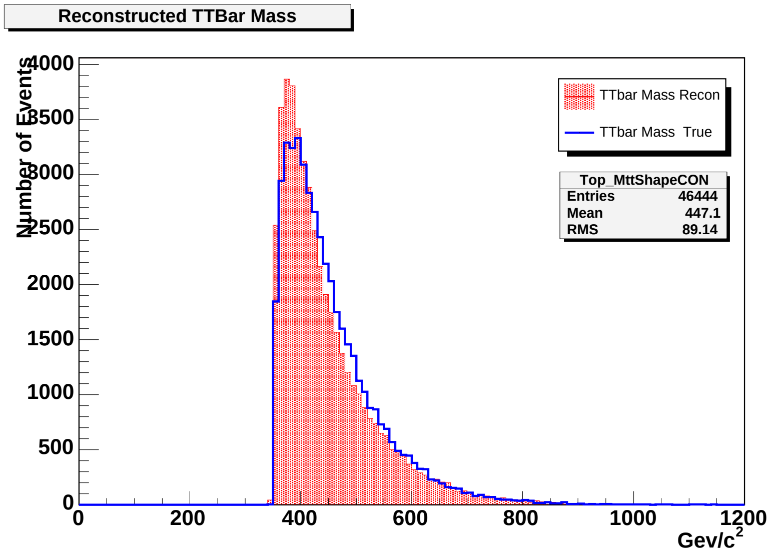

FIG. 1: The "true" $t\bar{t}$ mass compared to the reconstructed value

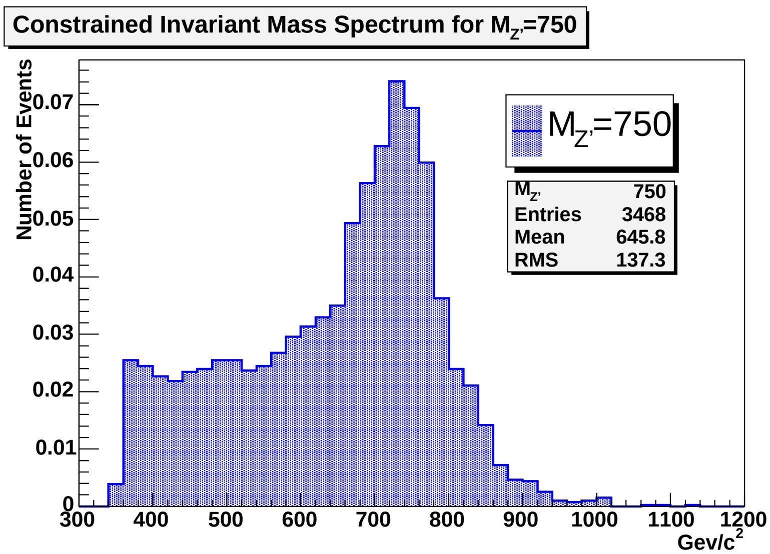

FIG. 2: The reconstructed mass for $Z' \to t\bar{t}$

The $M_{t\bar{t}}$ distribution for the decay of a 750 GeV$/c^2$ Z' with $\Gamma = 1.2\% \cdot M_{Z'} = 9$ GeV$/c^2$, is shown in Fig. 2. We see a resolution dominated Gaussian with width of roughly 50 GeV$/c^2$ near the expected mass, along with a low lying tail from events with incorrect parton assignments. The $M_{t\bar{t}}$ distribution for the non-top backgrounds is derived from Monte Carlo or data control samples for each subcomponent, and verified in the "sideband" samples of W+1 and W+2 jets. The χ^2 cut reduces the expected non-top background level by 9%.

We can combine the Z', top, and non-top models to establish our expected sensitivity. Fig. 3 shows a simulated $M_{t\bar{t}}$ distribution for the 1 fb^{-1} dataset in the case of a 750 GeV$/c^2$ Z' with $\sigma \cdot B = 1$ pb. The resonant component is clearly distinguishable.

The $M_{t\bar{t}}$ distribution found in the data is shown in Figs. 4, along with the model expectation. In the data, the χ^2 requirement removes 20 events leaving a final sample of 327 candidates. Figs. 5 shows the measurement on a semi-log scale. The data is consistent with the expectation from standard top pair production and non-top backgrounds. We proceed to set upper limits on unexpected contributions from $Z' \to t\bar{t}$.

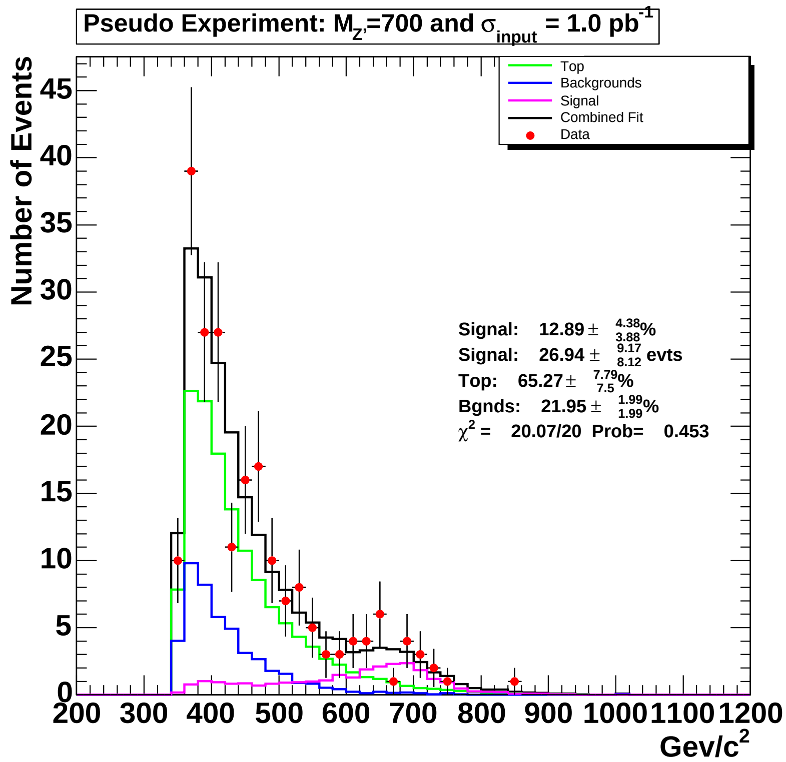

FIG. 3: Pseudo Experimental Data Set for $M_{Z'}$=700 and $\sigma_{Z'}^{input} = 1$ pb.

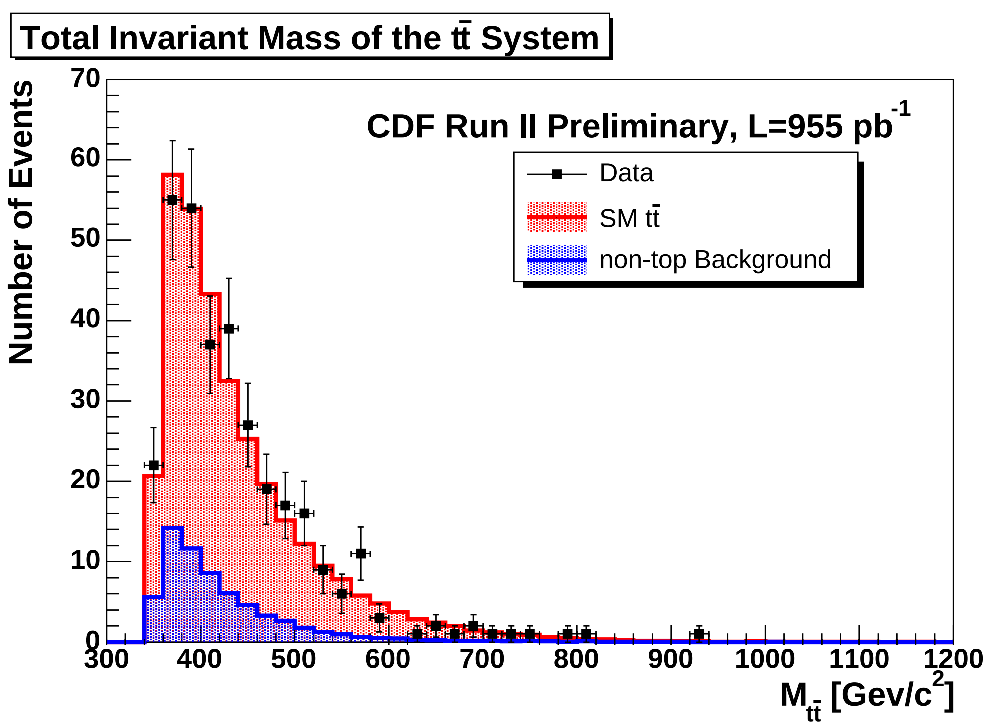

FIG. 4: The total top pair mass spectrum

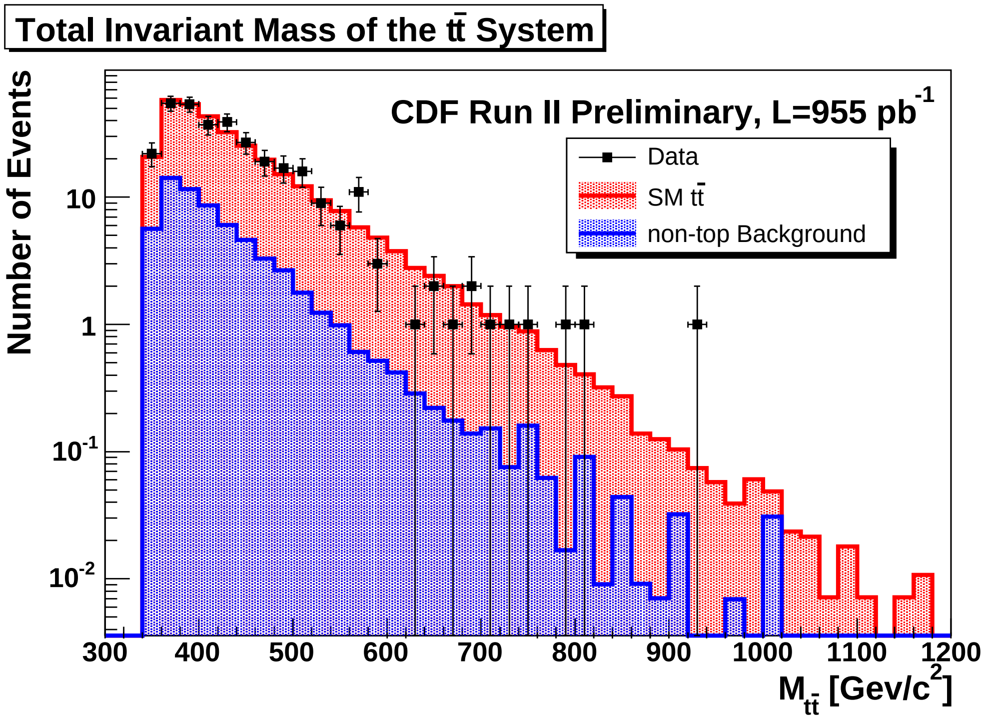

FIG. 5: Logarithmic total top pair mass spectrum

IV. ESTIMATE OF THE Z' COMPONENT

We assume the $M_{t\bar{t}}$ spectrum contains $Z' \to t\bar{t}$, standard $t\bar{t}$, and non-$t\bar{t}$ backgrounds, and perform a three parameter binned likelihood fit to the data. The expected population in each bin of $M_{t\bar{t}}$ is calculated from our models. In the $\mathrm{i^{th}}$ bin, we expect

$$\mu_i = \sigma_{Z'} \cdot \mathrm{A} \cdot \epsilon \cdot \int \mathcal{L}\mathrm{dt} \cdot \mathrm{P_{Z',i}} + \mathrm{N_{t\bar{t}}} \cdot \mathrm{P_{t\bar{t},i}} + \mathrm{N_{bkg}} \cdot \mathrm{P_{bkg,i}} \tag{1}$$

$\mathrm{A} \cdot \epsilon \cdot \int \mathcal{L}\mathrm{dt}$ is the acceptance, and efficiency for the $Z\prime$, along with the luminosity. The variables $\mathrm{P_{Z',i}}$, $\mathrm{P_{t\bar{t},i}}$, and $\mathrm{P_{bkg,i}}$ are the probabilities of observing a signal event, $t\bar{t}$ event and non-$t\bar{t}$ background event in this bin. The parameters $\mathrm{N_{t\bar{t}}}$ and $\mathrm{N_{bkg}}$ are the number of SM $t\bar{t}$ and the non-$t\bar{t}$ background events. A likelihood function L is written

$$\mathrm{L} = \prod_{\mathrm{i,k}} \mathcal{P}_i(\mathrm{n_i}|\mu_i) \cdot G(\nu_\mathrm{k}|\bar{\nu}_\mathrm{k}, \sigma_{\nu_\mathrm{k}}) \tag{2}$$

$\mathcal{P}_i(\mathrm{n_i}|\mu_i)$ is the Poisson probability for observing n events in a bin where μ is expected. The ν_k, which include the non-top background normalization N_{bkg}, b-tag efficiency, acceptances and luminosities, are the nuisances. The functions $G(\nu_\mathrm{k}|\bar{\nu}_\mathrm{k}, \sigma_{\nu_\mathrm{k}})$ are Gaussian constraints holding the ν_k to their nominal central values $\bar{\nu}_\mathrm{k}$, within their uncertainties σ_{ν_k}. Acceptances and b-tag efficiency, as well as non-top background levels, are constrained to the accepted values from the top cross section measurement. We find $\sigma_{Z'}$, $\mathrm{N_{t\bar{t}}}$ and $\mathrm{N_{bkg}}$ that maximize the likelihood function. For the central values of $\mathrm{N_{t\bar{t}}}$ and $\mathrm{N_{bkg}}$, the value of $\sigma_{Z'}$ that contains 95% of the area of the likelihood function is our 95% CL upper limit on $\sigma \cdot B$ for $Z' \to \mathrm{t\bar{t}}$.

The procedure is tested with large numbers of simulated data sets like the one shown in Fig. 3, and showed to return the correct he Z' cross section for inputs ranging from 0 and 4 pb, over our complete Z' mass range. By injecting Poisson variations into the component weights, we can estimate our sensitivity: we expect to exclude, at 95% CL, cross-sections down to 0.6 pb at $M_{Z'} = 700$ GeV$/c^2$.

The model dependent systematic shape uncertainties are small. The main sources are the jet energy scale (JES) and assumed top mass, with smaller contributions from ISR, FSR, non-top background mix, and W-Q2. We generate separate pseudo samples where we vary these parameters by the uncertainties and calculate the offset in the fitted cross section for the null measurement. The offsets are added in quadrature and used as a cross-section dependent width of the Gaussian function which is convolved with the likelihood. The net effect is to increase the limits by roughly 0.2pb at $M_{Z'} = 450\text{GeV}/c^2$, decreasing to 0.1pb at higher Z' masses.

V. RESULTS

$M_{Z'}$	Expected Limit (956pb^{-1})	Data Limit (956pb^{-1})
450	$2.27^{+0.79}_{-0.57}$	3.39
500	$1.92^{+0.63}_{-0.40}$	2.72
550	$1.37^{+0.45}_{-0.30}$	1.57
600	$0.97^{+0.33}_{-0.18}$	0.83
650	$0.78^{+0.24}_{-0.13}$	0.65
700	$0.70^{+0.14}_{-0.12}$	0.64
750	$0.64^{+0.15}_{-0.11}$	0.61
800	$0.58^{+0.15}_{-0.07}$	0.60
850	$0.55^{+0.10}_{-0.05}$	0.57
900	$0.55^{+0.08}_{-0.06}$	0.57

TABLE I: Results for the Limit on the cross section of $\sigma_{Z'}$ as a function of $M_{Z'}$

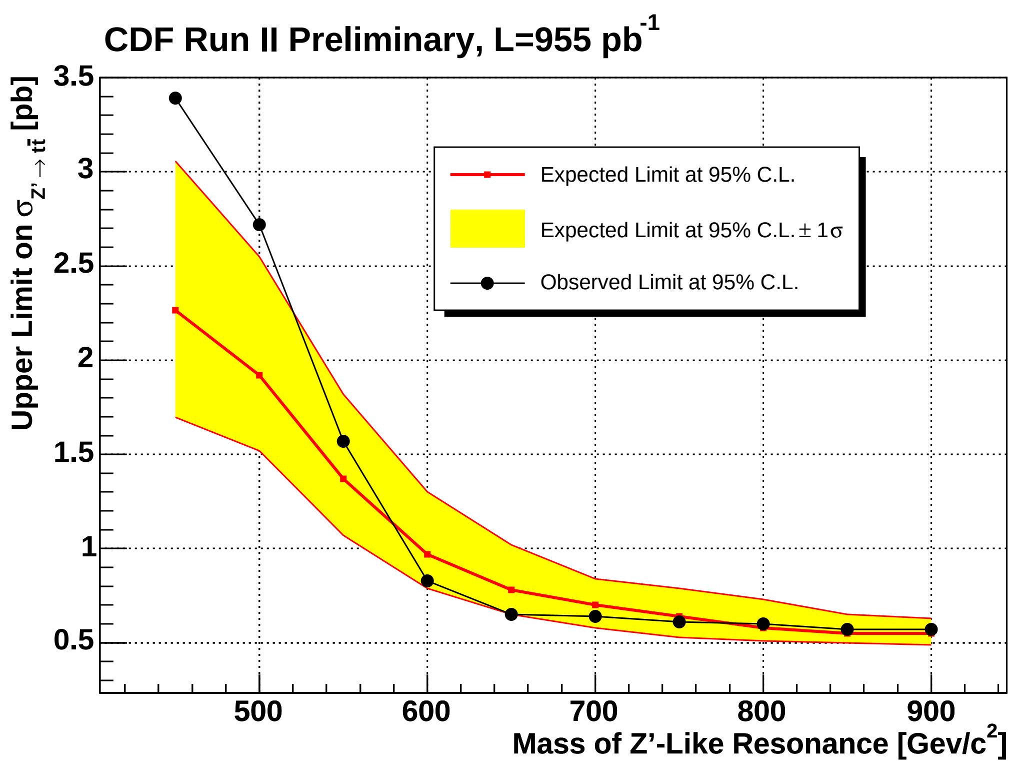

FIG. 6: Upper limits on the production cross section for $Z' \to t\bar{t}$ in data plotted along with the SM expected values.

Our result is summarized in Fig. 6 and Table I. The 95% CL upper limit on $\sigma \cdot B(Z' \to t\bar{t})$ is shown as a function of $M_{Z'}$ as the solid black line. The red curve is the expected 95%CL upper limit, calculated from the model analysis. The yellow band denotes the $\pm1\sigma$ uncertainties on the expected upper limit. We find that the contribution of any "Z-like" state decaying to $t\bar{t}$ is less than 0.7 pb for all $M_{Z'}$ above 700 GeV/c^2. At lower masses the sensivity is decreased by the large *ttbar* background, and our limit is reduced to roughly 3 pb. The measurement is consistent with expectations, with only a modest 1 σ departure in the low mass region (450 to 500 GeV/c^2). We find no evidence for new contributions to the $M_{t\bar{t}}$ spectrum in p$\bar{\text{p}}$ collisions at $\sqrt{s} = 1.96$ TeV.

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